Modeling Supernova Explosions

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Supernovae are one of the biggest explosions in the universe. Their ejecta plow through the Milky Way, producing spherically shaped “remnants” composed of supernova debris mixed with dust in our Galaxy. The shocks produced by this motion heat the debris, causing it to radiate. Astronomers detect this radiation and use their observations to study both the supernova explosion and the interstellar matter through which the supernova plows.

A few nearby supernova remnants have been studied in space, time, and composition. We can use these observations to not only study supernova explosions, but also to study hydrodynamics and test the ability of our numerical codes to model the detailed mixing in the explosive phenomena. The wealth of observational data, from the time evolution of specific knots in the ejecta to detailed composition measurements, provides a number of checks, allowing us to overcome the uncertainties in the initial explosion and, ultimately, to test our hydrodynamic codes.

This project, currently at its initial stages, is set to model the propagation of the supernova explosion, paying particular attention to the turbulence and elemental mixing that occurs in this ejecta. Figure 1 shows an isosurface of the abundance of a radioactive isotope of nickel (^{56}Ni) within the explosion ejecta (shading) from an asymmetric explosion using the three-dimensional (3D) Smooth Particle Hydrodynamics code (SNSPH) developed in T-6 [1]. The asymmetry in the explosion mixes the ^{56}Ni well out into the outer layers of the ejecta and the amount of mixing provides an ideal diagnostic of the supernova explosion.

But our modeling of this mixing is very sensitive to the hydrodynamic algorithm. To test these calculations, we have begun detailed comparison calculations between the SNSPH and RAGE [2] codes. In our first suite of comparison calculations, we compare 1D simulations using a 1D Lagrangian code [3] to RAGE. Figure 2 (top) shows a comparison of the velocity profiles

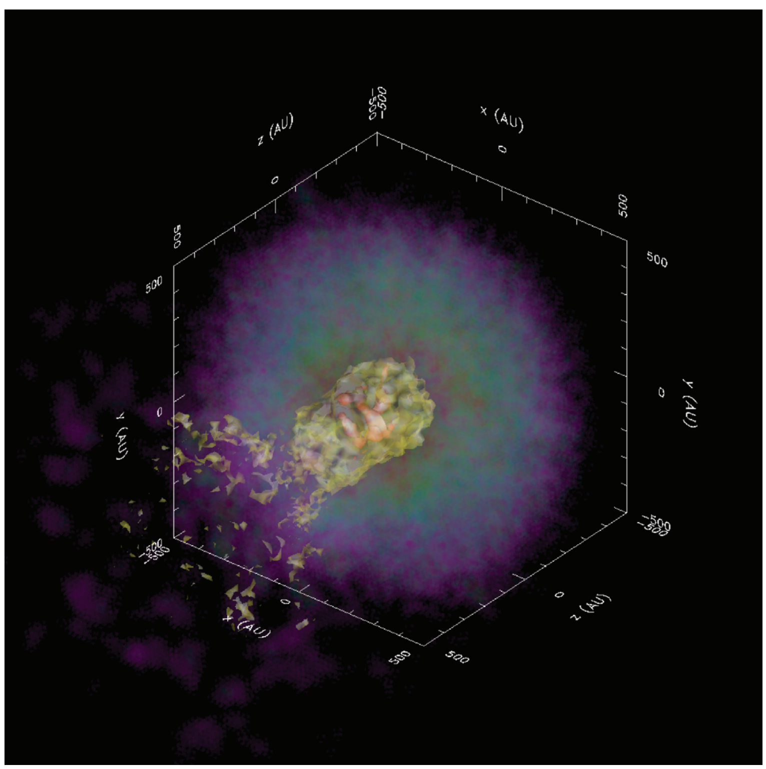

Figure 1— ***An isosurface of the abundance of a radioactive isotope of nickel (^{56}Ni) within the explosion ejecta (shading) from an asymmetric explosion using the 3D Smooth Particle Hydrodynamics code (SNSPH) developed in T-6 [1].***

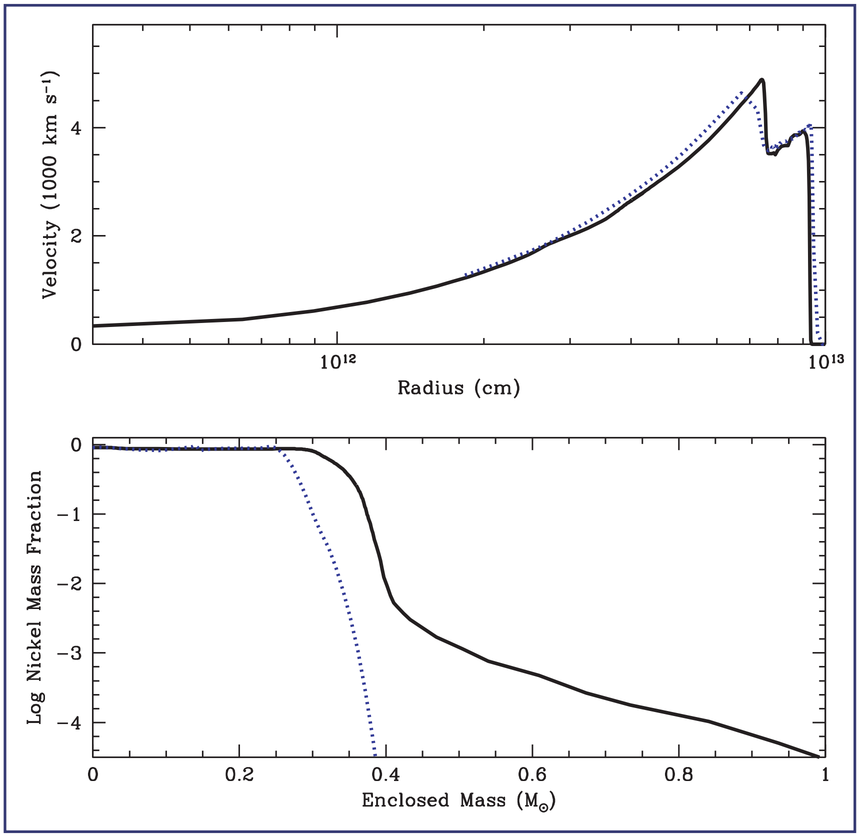

Figure 2— (top) A comparison of the velocity profiles of the ejecta at two different times during the explosion. (bottom) The nickel abundance distribution vs enclosed mass for these codes for these same two time slices plus one final time slice as the shock breaks out of the star.

of the ejecta at the end of our simulation. Such an explosion is a slight variant over the standard Sedov test used to calibrate codes. It differs by including a complex equation of state and a nonpower-law density profile. It provides a much more rigorous test of these hydrodynamics codes. Figure 2 (bottom) shows the nickel abundance distribution versus enclosed mass for these codes for this same time. Both simulations are using extremely low resolution (roughly 200 zones in the Lagrangian simulation and 500 zones in the RAGE calculation). This resolution is what we will be able to achieve in our 3D calculations. In the Lagrangian calculation, the 56Ni distribution does not change with time. The spreading of the ^{56}Ni in the RAGE calculations is due to numerical diffusion. It is this artificial diffusion that we must understand and constrain to successfully complete this validation experiment.

[1] C.L. Fryer and M.S.Warren, "Modeling Core-Collapse Supernovae in Three Dimensions," *Ap. J.* **574**, L65 (2002).
[2] R.L. Holmes, et al. "Richtmyer-Meshkov Instability Growth: Experiment, Simulation and Theory," *J. Fluid Mech.* **389**, 55 (1999).
[3] M. Herant, et al., "Inside the Supernova: A Powerful Convective Engine," *Ap. J.* **435**, 339b (1994).

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